

1 TITLE

2 Al/Cu/Mg/Ag alloy with Si, semi-finished product from such an
3 alloy as well as method for the production of such a semi-
4 finished product

5
6 CROSS REFERENCE APPLICATIONS

7 This application is a national phase application
8 claiming priority from PCT application no. PCT/EP2002/07193
9 filed on 29 June 2002.

10
11 FIELD OF INVENTION

12 Subject matter of the invention is an Al/Cu/Mg/Mn Alloy-
13 alloy for the production of semi-finished products with high
14 static and dynamic strength properties. The invention
15 further relates to semi-finished products manufactured from
16 such an alloy with high static and dynamic strength
17 properties as well as to a method for the production of such
18 a semi-finished product.

19
20 BACKGROUND OF THE INVENTION

21 Aluminum alloys having a high static and dynamic bearing
22 capacity, ~~are for example~~ include the alloys AA 2014 and AA
23 2214. ~~From these Al alloys in the artificially aged state~~
24 ~~for example drop~~Drop-forged parts for wheel and brake systems
25 of airplanes are manufactured from these Al alloys in the
26 artificially aged state~~are manufactured. While the listed~~
27 ~~strength properties of the~~ The semi-finished products
28 ~~produced of such an~~from the alloy intrinsically have the
29 listed strength properties of ~~are the alloys an intrinsic~~
30 ~~characteristic of the semifinished product, especially at~~
31 lower temperatures, However, at temperatures of more than

1 100° C these properties decrease more rapidly than is the
2 case with alloys of the group AA 2618.

3 Semi-finished products of ~~such the~~ alloys of group AA
4 2618 have better high-temperature stability and are utilized
5 ~~for example for a variety of uses such as~~ compressor
6 impellers for rechargeable ~~Diesel-diesel~~ engines or for
7 rotors of ultracentrifuges. However, at temperatures below
8 100°C, the aluminum alloys of the group AA 2014 and AA 2214
9 have greater bearing capacity.

10 In ~~the case of the~~ wheel brake system of airplanes
11 considerable heat is generated during the braking process.
12 This leads to temperature increases even in the wheels, which
13 typically are fabricated of an AA 2014 or AA 2214 alloy.
14 These can cause early overageing of this alloy and, ~~entailed~~
15 ~~therein,~~ lead to a severe limitation of the service life of
16 the structural part.

17 In ~~the case of~~ compressor impellers the transitions to
18 titanium alloys ~~have~~ has been made in order to ~~lend~~ give the
19 compressor impellers ~~produced therefrom~~ the necessary static
20 and dynamic strength properties even at increased
21 temperatures. However, employing titanium is expensive and
22 ~~especially for this reason~~ is therefore not suitable for the
23 production of airplane wheels. Furthermore, titanium is
24 less well suited as a material for wheels due to its limited
25 thermal conductivity, ~~titanium is less well suited as a~~
26 ~~material for wheels.~~

27 The problematic described above is not new. Therefore,
28 for many years there has been the wish for an Al alloy, which
29 combines the high strength properties of the alloys AA 2014
30 or AA 2214 at ambient temperature and the thermal stability
31 of the alloys AA 2618 or 2618 A.

1 ~~simultaneously~~while also having very good mechanical
2 fracturing properties. These properities are attained in
3 particular at a copper-magnesium ratio between 5 and 9.5, in
4 particular at a ratio between 6.3 and 9.3. The copper
5 content is preferably between 3.8 and 4.2 wt. % and the
6 magnesium content between 0.45 and 0.6 wt. %. The copper
7 content is markedly below the maximum solubility for copper
8 in the presence of the claimed magnesium content. As a
9 consequence, the fraction of insoluble copper-containing
10 phases is very low, also taking into consideration the
11 remaining alloy and companion elements. Thereby an
12 improvement is obtained with respect to the dynamic
13 properties and the fracture toughness of the semi-finished
14 products manufactured from such an alloy.

15 In contrast to the known AA alloys 2014 and 2219, a
16 portion of the claimed alloy is silver with contents between
17 0.3 and 0.7 wt. %, preferably 0.45 and 0.6 wt. %. In the
18 interaction with silicon (0.3 - 0.7 wt. %, preferably 0.4 -
19 0.6 wt. %) the hardening takes place via the same mechanisms
20 as in silver-free Al/Cu/Mg alloys. However, it has been
21 found that with lower silicon contents, the course of
22 precipitation is different due to the addition of silver.

23 While the semi-finished products manufactured from such
24 an alloy have good high-temperature stability and creep
25 resistances under cooler conditions, ~~however,~~ they do not
26 meet the desired requirements. Only silicon contents above
27 0.3 wt. % suppress the otherwise typical change of the
28 precipitation behavior of Al/Cu/Mg/Ag alloys, such that
29 unexpectedly higher strength values can be attained without
30 having to give up the high-temperature stability and the

1 creep resistance with the Cu and Mg contents according to the
2 invention.

3 The manganese content of the claimed alloy is 0.1 to 0.5
4 wt. %, preferably 0.2 - 0.4 wt. %. In the case of alloys
5 with higher manganese contents undesirable precipitation
6 processes were found with long-term high-temperature stress,
7 which led to a decrease of strength. For this reason the
8 manganese content is limited to 0.4 wt. %. However,
9 manganese is fundamentally required as an alloy component
10 ~~fundamentally required for the control of the grain~~
11 structure.

12 To balance the reducing effect of ~~managese~~manganese with
13 respect to the grain structure control, the alloy contains
14 zirconium between 0.10 - 0.25 wt. %, preferably 0.14 - 0.20
15 wt. %. The precipitating zirconium aluminides, as a rule,
16 are developed even more finely dispersed than manganese
17 aluminides. Moreover, Itit ~~was moreover~~ found that the
18 zirconium aluminides contribute to the thermal stability of
19 the alloy.

20 For grain sizing 0.05 - 0.15 wt. %, preferably 0.10 -
21 0.15 wt. % of titanium is added. The titanium is usefully
22 added in the form of an Al/5Ti/1B prealloy, whereby boron is
23 automatically included in the alloy. ~~Therefrom finely~~ Finely
24 dispersed, insoluble titanium diborides are formed therefrom.
25 These contribute to the thermal stability of the alloy.

26 The alloy can comprise maximally 0.15 % iron, preferably
27 0.10%, as an unavoidable contamination.

28

29 ~~In the following, test results will be described with~~
30 ~~reference to the attached figures. These depict~~

31 BRIEF DESCRIPTION OF THE DRAWINGS

1
2 Fig. 1 is a diagram representing graph showing the 0.2% yield
3 strength and the tensile strength of the alloy
4 according to the invention in state T6 in comparison
5 to prior known alloys, as a function of the test
6 temperature.7

7
8 Fig. 2 is a diagram representing graph showing the long-time
9 stress to rupture strength of the alloy according to
10 the invention in state T6 in comparison to known
11 alloys.7

12
13 Fig. 3 is a diagram representing graph showing the 0.2% yield
14 strength and the tensile strength of airplane wheels
15 manufactured from the alloy according to the
16 invention in comparison to such manufactured from
17 known alloys.7 and

18
19 Figs. 4a and 4b are diagrams graphs representing showing the
20 fatigue strength of the alloy according to the
21 invention in comparison to a known alloy in state T6
22 at ambient temperature and at a temperature of 200°
23 C.

24
25 Before explaining the disclosed embodiment of the
26 present invention in detail, it is to be understood that the
27 invention is not limited in its application to the details of
28 the particular arrangement shown, since the invention is
29 capable of other embodiments. Also, the terminology used
30 herein is for the purpose of description and not of
31 limitation.

1

2 DETAILED DESCRIPTION OF THE INVENTION

3 Table 1 reproduced below shows the chemical composition
4 of four alloys (B, C, D, E) according to the invention as
5 well as the composition of the alloys AA 2214 and AA 2618
6 examined as a comparison (data in wt. % (n.d.: not
7 determined)

8 **Table 1**

9

Alloy	Si	Fe	Cu	Mn	Mg	Ni	Zn	Ti	Ag	Zr	V
B	0.47	0.08	4.40	0.200	0.58	0.003	0.048	0.135	0.45	0.150	0.018
C	0.47	0.08	3.64	0.210	0.59	0.003	0.015	0.115	0.52	0.150	0.017
D	0.47	0.08	3.87	0.200	0.61	0.003	0.015	0.117	0.52	0.150	0.019
E	0.52	0.08	4.14	0.200	0.61	0.003	0.02	0.115	0.44	0.150	0.018
AA 2214	0.77	0.17	4.29	0.883	0.57	0.003	0.031	0.024	0.003	0.007	n.d.
AA 2618	0.22	1.1	2.58	0.020	1.53	1.007	0.043	0.059	0.003	0.002	n.d.

10

11 From these alloys semi-finished products were manufactured
12 following the method steps listed below:

13 a) casting of an ingot from an alloy,
14 b) homogenizing the cast ingot at a temperature, which is as
15 close under the incipient melting temperature of the alloy as
16 is possible, for a length of time adequate to attain
17 maximally uniform distribution of the alloy elements in the
18 cast structure,
19 c) hot working of the homogenized ingot by forging at a
20 block temperature of approximately 420°C,

1 d) solution treatment of the semi-finished product worked by
 2 forging at temperatures sufficiently high to bring the alloy
 3 elements necessary for the hardening into solution such that
 4 they are uniformly distributed in the structure, with the
 5 solution treatment taking place in a temperature range ~~[sic]~~
 6 of 505°C over a time period of 3 hours,
 7 e) quenching of the solution-treated semi-finished product
 8 in water at ambient temperature,
 9 f) cold working of the quenched semi-finished products by
 10 cold upsetting by 1 to 2%, and
 11 g) artificial ageing of the quenched semi-finished product
 12 at a temperature of 170°C over time period of 20 to 25 hours.
 13 The open-die forged pieces produced in this manner were
 14 subsequently tested for their properties in the
 15 ~~artificially~~artificially aged state T6.

16 Table 2

17 Strength values at ambient temperature

Fracture toughness at ambient temp.

Alloy	Sample direction	R _{p02} (MPa)	R _m (MPa)	A ₅ (%)	Sample direction	K _{IC} (MPa√m)
C	L	448	485	11.2	T-L	31.3
	LT	427	471	7.2	S-L	29.5
	ST	417	479	6.3	S-T	32.2
D	L	456	495	10.7	T-L	28.3
	LT	434	478	8.0	S-L	29.1
	ST	429	484	5.5	S-T	29.6
E	L	454	494	9.9	T-L	26.1
	LT	446	493	6.4	S-L	25.5
	ST	438	494	4.9	S-T	26.9
AA 2214	L	444	489	9.7	T-L	24.2
	LT	439	483	6.4	S-L	25.9
	ST	429	480	5.8	S-T	27.3

AA 2219	L	286	408	16.7	T-L	31.1
	LT	288	403	8.4	S-L	34.4
	ST	366	455	5.0	S-T	32.3
AA 2618	L	389	443	5.1	T-L	19.2
	LT	383	437	4.7	S-L	16.7
	ST	376	427	4.1	S-T	19.3

Table 3

Alloy		E			AA 2214			AA 2618		
R_{test} (°C)	T_{hold} (h)	$R_{p0.2}$ (Mpa)	R_m (Mpa)	A_5 (%)	$R_{p0.2}$ (Mpa)	R_m (Mpa)	A_5 (%)	$R_{p0.2}$ (Mpa)	R_m (Mpa)	A_5 (%)
20	1	454	494	9.9	444	489	9.6	380	434	6.5
50	1	453	493	12.6	443	485	9.8	382	433	6.1
100	1	449	474	13	425	458	11	374	423	6.5
150	1	404	417	14.3	403	424	13.6	366	404	7.6
170	1	403	416	16.3	382	400	13.6	382	389	9.6
200	1	355	372	18	348	368	13.8	340	359	12.2
220	1	340	351	18	324	344	14.2	301	332	12.4
250	1	268	282	19	250	268	16.1	282	300	14.7

Definitions sample directions:

L= longitudinal direction: parallel to the main form change direction

LT= long transverse direction: parallel to the width direction

ST= short transverse direction: parallel to the thickness direction

The improved strengths of the alloy according to the invention (for example alloy E) is clearly evident in Tables 2 and 3. For example, while the prior known alloy AA 2214 shows good strength values at ambient temperature, ~~however it~~

1 ~~does not~~ at higher temperatures ~~it does not~~. Moreover, the
2 creep resistance ~~as well as~~ and the fracture toughness are ~~not~~
3 ~~only~~ markedly better at ambient temperature, ~~but especially~~
4 ~~also~~ and at higher temperatures, in the claimed alloy ~~than~~
5 incompared to the prior known alloys. This comparison makes
6 ~~further clear~~ that the tested prior known alloys have ~~only~~
7 good properties only with respect to a single strength
8 parameter. ~~Not in~~ In no a single case do these ~~the prior~~
9 alloys have good properties in all relevant strength values
10 at ambient temperature as well as ~~also~~ at increased
11 temperatures. Just as is the case with the fatigue
12 properties, the creep resistance of this prior known alloy is
13 not satisfactory. Very good properties over all tested
14 strength parameters could only be determined in the case of
15 the alloy according to the invention.

16 ~~The associated representation of~~ Figure 1 also makes
17 graphically clear the better strength properties of the alloy
18 (alloy E) according to the invention compared to the known
19 alloys (AA 2214 as well as AA 2618). The results showed
20 unexpectedly that the strength values of alloy E are better
21 even at temperatures below 100°C than those of the known
22 alloy AA 2214, which is known for its especially high
23 strength values in this temperature range.

24 ~~Moreover~~ Additionally, the creep resistance of the semi-
25 finished products was tested. Table 4 shown below provides
26 the test results (LMP: Larson Miller parameter) in summary:

27

28 Table 4:

Alloy											
E				AA 2214				AA 2618			
T _{test}	σ _{test}	t _{fracture}	LMP	T _{test}	σ _{test}	t _{fracture}	LMP	T _{test}	σ _{test}	t _{fracture}	LMP

(°C)	(MPa)	(h)	(-)	(°C)	(MPa)	(h)	(-)	(°C)	(MPa)	(h)	(-)
180	185	2513	10.60	205	200	30	10.27	205	183	10	10.04
	167	4762	10.82		190	50	10.38		179	50	10.38
					181	100	10.52		175	100	10.52
					130	500	10.85		163	500	10.85
					100	800	10.95		159	1000	11.00

1

2 Plotted graphically, the markedly better long-time stress to
3 rupture strength of the alloy in the T6 state in comparison
4 to the known alloys AA 2214 and AA 2618 ~~also in the T6 state~~
5 is apparent. This is ~~reproduced in the diagram of~~ shown in
6 Figure 2 as time-compensated temperature representation. The
7 especially good creep resistance of the alloy according to
8 the invention could not be foreseen, ~~such that~~ making this
9 result ~~is~~ surprising.

10 _____ Within the scope of testing the method steps for the
11 production of these semi-finished products, it was found that
12 comparable material properties of the produced semi-finished
13 products can be attained if the step of hot working is
14 carried out at a block temperature between 320°C to 460°C.
15 The hot working can be either forging or rolling. The step
16 of quenching of the solution treated semi-finished product
17 can take place in a temperature range between ambient
18 temperature and 100°C (boiling) in water. It is also
19 possible to utilize a water-glycol mixture for the quenching,
20 the temperature of which, ~~however,~~ should not exceed 50°C.

21 ~~_____ Instead of the previously described step of cold working~~
22 ~~through cold upsetting during forging, as a~~ cold working
23 step ~~also of~~ a drawing out by 1% to 5% can be carried out in
24 the case of extruded or rolled products for the purpose of

1 reducing the intrinsic stresses due to the quenching instead
2 of the previously described step of cold working through cold
3 upsetting during forging. The step of artificial ageing can
4 be carried out over a time period of 5 to 35 hours,
5 preferably between 10 and 25 hours, in a temperature window
6 between 170°C and 210 °C.

7 During further tests strand-cast ingots were produced as
8 described above and airplane wheels manufactured by drop
9 forging in the preforge die and finish forge die at a
10 temperature of 410 to 430°C. These wheels were subsequently
11 solution treated at 505°C, quenched in a mixture of water and
12 glycol of ambient temperature and thermally age-hardened at
13 170°C for 20 hours. ~~For These were compari~~compared to son
14 mass-produced airplane wheels of the alloy AA 2214~~were used.~~
15 Samples were taken from the wheels produced of the claimed
16 alloy and of the conventional alloy ~~At at sites distributed~~
17 ~~over the circumference samples were removed from the wheels~~
18 ~~produced of the claimed alloy and of the conventional alloy,~~
19 and tested for their tensile strength. The results ~~is~~are
20 ~~graphically shown in Figure 3.~~ It can ~~be~~ clearly be seen
21 that the alloy E according to the invention yields better
22 values compared to the known alloy AA 2214.

23 Fatigue tests in comparable samples of the two cited
24 alloys also show that the wheels produced from the claimed
25 alloy attain markedly better values than the wheels produced
26 from the alloy AA 2214. This applies to the fatigue tests
27 carried out at ambient temperature (cf. Figure 4a) as well as
28 to the fatigue tests carried out at a test temperature of
29 200°C (cf. Figure 4b).

30 The description of the claimed invention ~~surprisingly~~
31 makes clear that surprisingly these the claimed alloys have

1 not only high dynamic and static strength values, but that
2 ~~these they have in particular also an~~ especially good high-
3 temperature stability, fracture toughness and creep
4 resistance. ~~Therefore this~~ This alloy is therefore is in
5 particularly suitable for the production of semi-finished
6 products, which must meet precisely these requirements, such
7 as ~~for example~~ airplane wheels or compressors.

8 Although the present invention has been described with
9 reference to the disclosed embodiments, numerous
10 modifications and variations can be made and still the result
11 will come within the scope of the invention. No limitation
12 with respect to the specific embodiments disclosed herein is
13 intended or should be inferred. Each apparatus embodiment
14 described herein has numerous equivalents.